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Nanostructure growth, characterization and applications

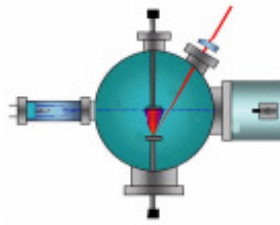
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# Control and characterization of self-assembled Ge quantum dots grown by pulsed laser deposition

**Mohammed Hegazy & Hani Elsayed-Ali**

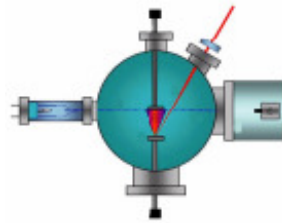
**mhegazy@odu.edu    helsayed@odu.edu**

Old Dominion University, Physical Electronics Research  
Institute, Electrical and Computer Engineering Department,  
Norfolk, VA-23529

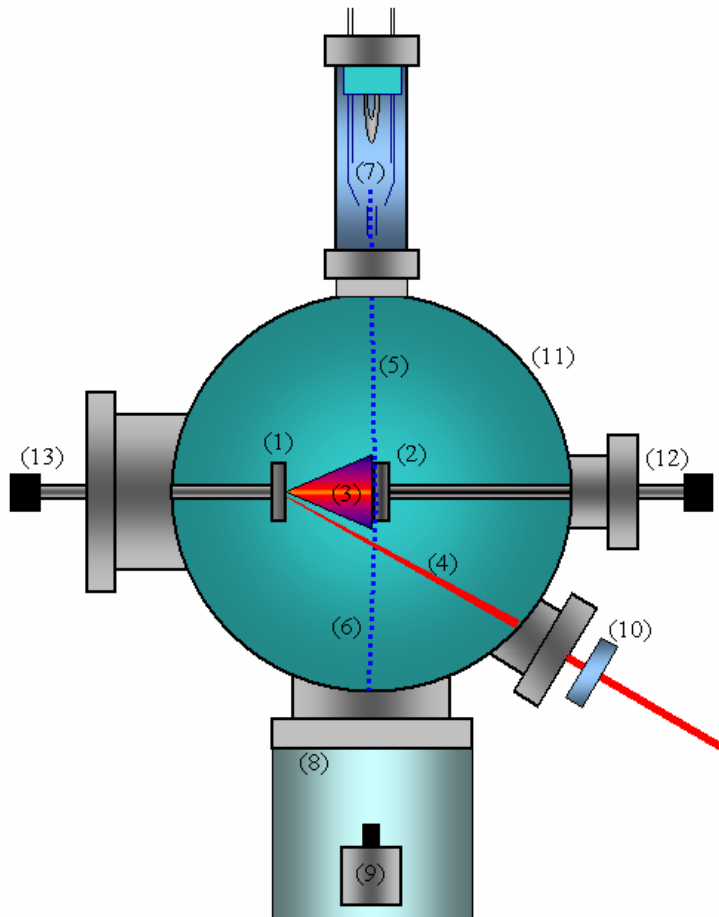


## **Abstract**

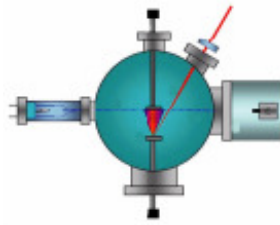
- Growth dynamics and morphology of self-assembled Ge QD on Si(100)-(2x1) by nanosecond PLD
- *In situ* RHEED and post deposition AFM
- Effects of laser fluence and substrate temperature on QD
- 3x laser fluence → 20x QD density & 0.3x average size  
→ shape: large huts → domes
- Temperature effect:
  - 150 °C: misaligned QDs
  - 400 °C & 500 °C: oriented huts and domes
  - 600 °C: QDs on textured surfaces



# *Pulsed Laser Deposition (PLD)*

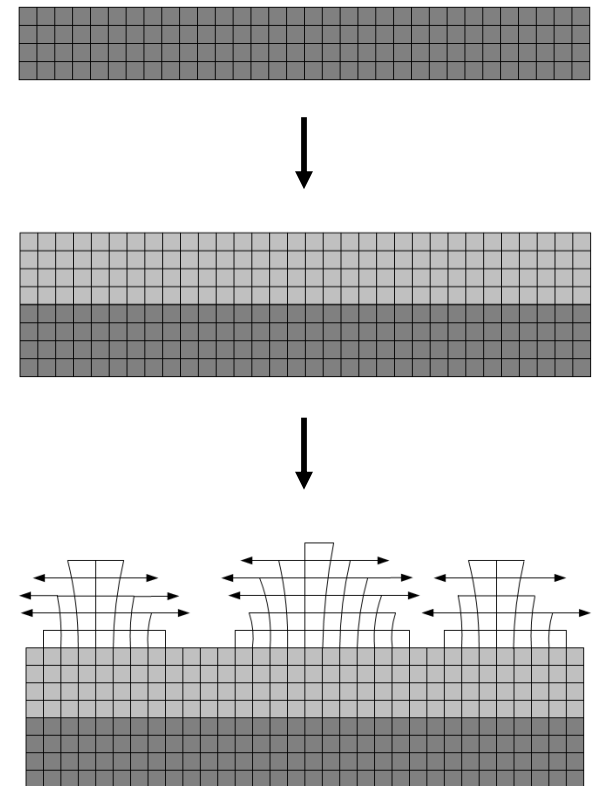


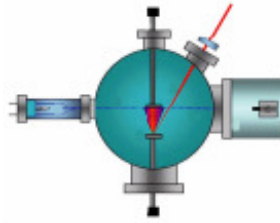
- (1) Target
- (2) Substrate
- (3) Ablated species "Plume"
- (4) Focused laser
- (5) Electron probe
- (6) Diffracted electrons
- (7) Electron gun
- (8) Phosphor screen
- (9) CCD camera
- (10) Focusing lens
- (11) Ultrahigh vacuum chamber
- (12) Substrate manipulator
- (13) Target manipulator



## *Self-assembly of Ge QDs on Si(100)-2x1*

- Stranski-Krastanow (SK) growth in lattice-mismatched systems
- Epitaxial layer first formed
- Strain increases with film thickness
- At critical thickness  $\rightarrow$  3D relieves strain
- Hut clusters first form
- Huts  $\rightarrow$  domes with growth





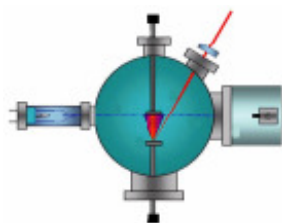
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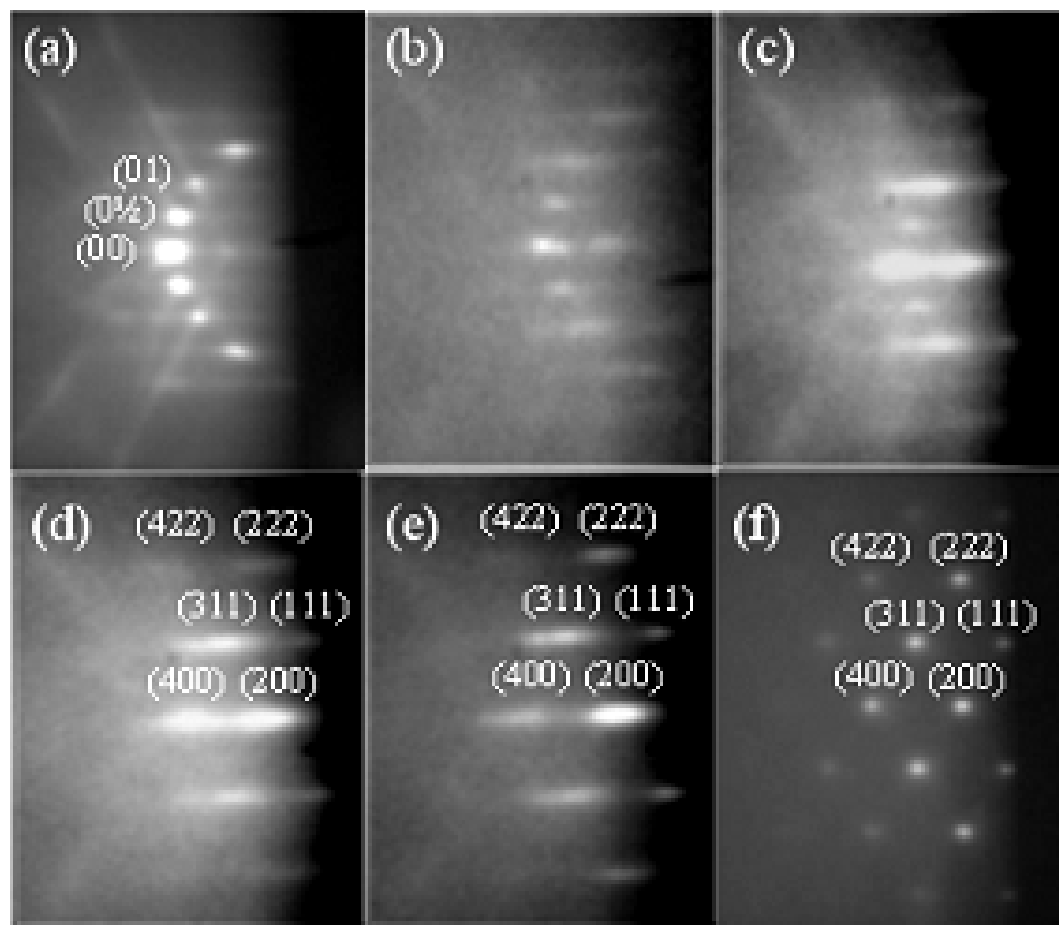
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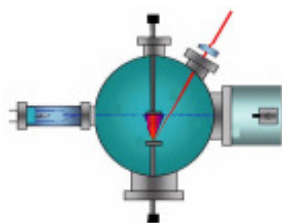
# *I. Ge QD growth dynamics by PLD*



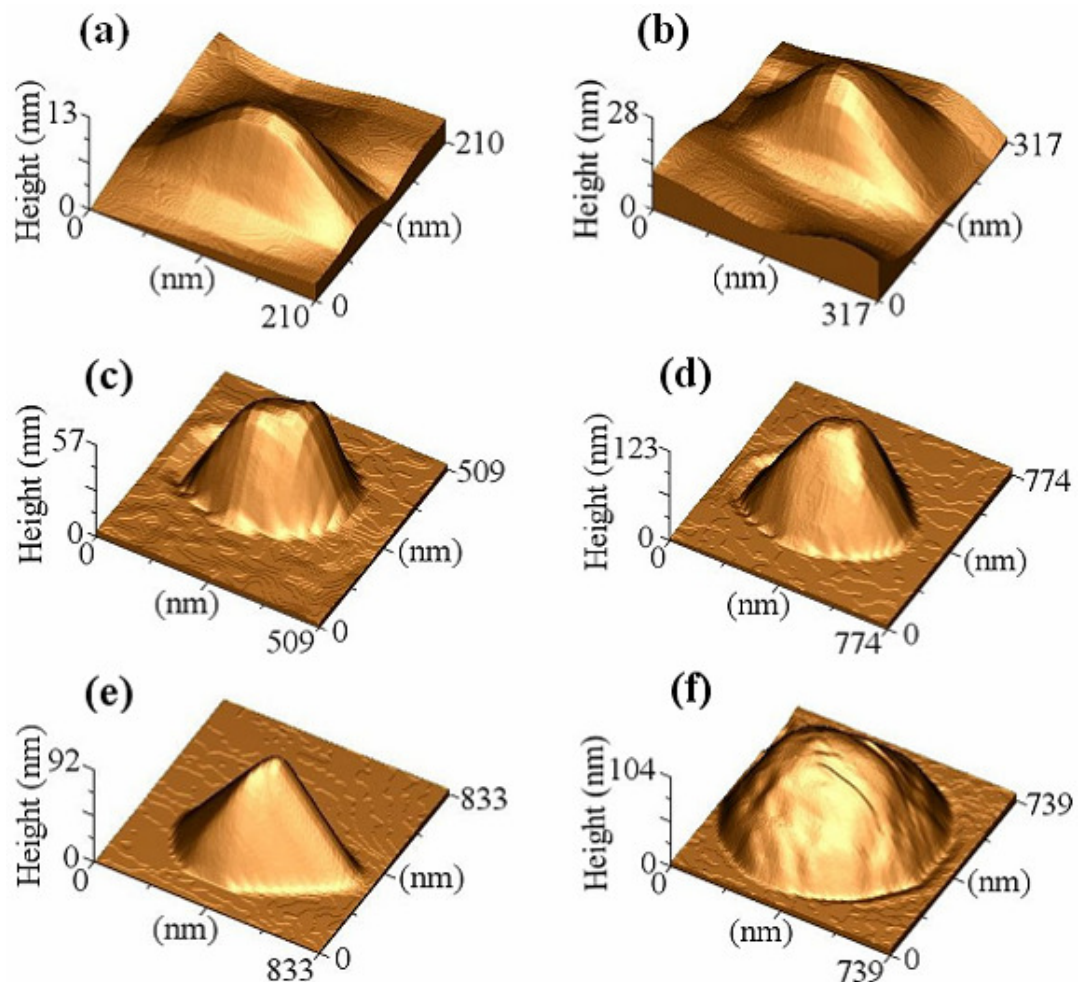
## *RHEED monitors growth dynamics*

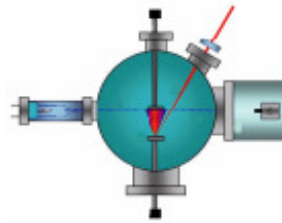


Deposition at 400 °C, 23 J/cm<sup>2</sup>, 10 Hz. (a) (2×1) substrate, (b) ~3.3 ML, (c) ~4.1 ML, (d) ~6 ML, (e) ~9.3 ML, and (f) ~13 ML

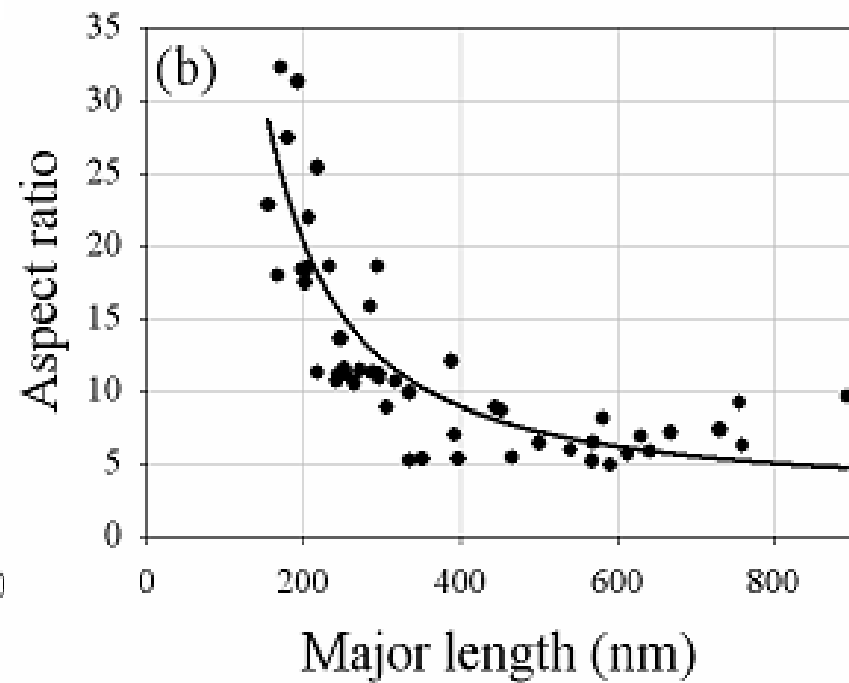
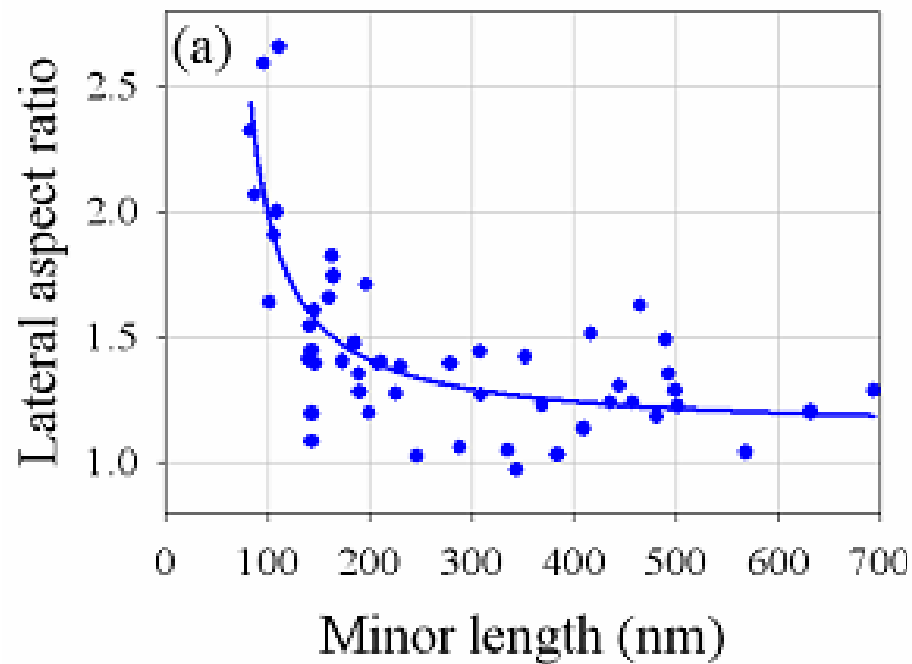


## *Morphology studied by ex-situ AFM*

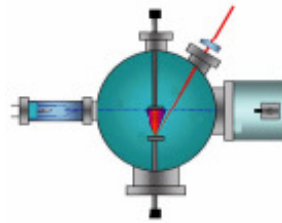




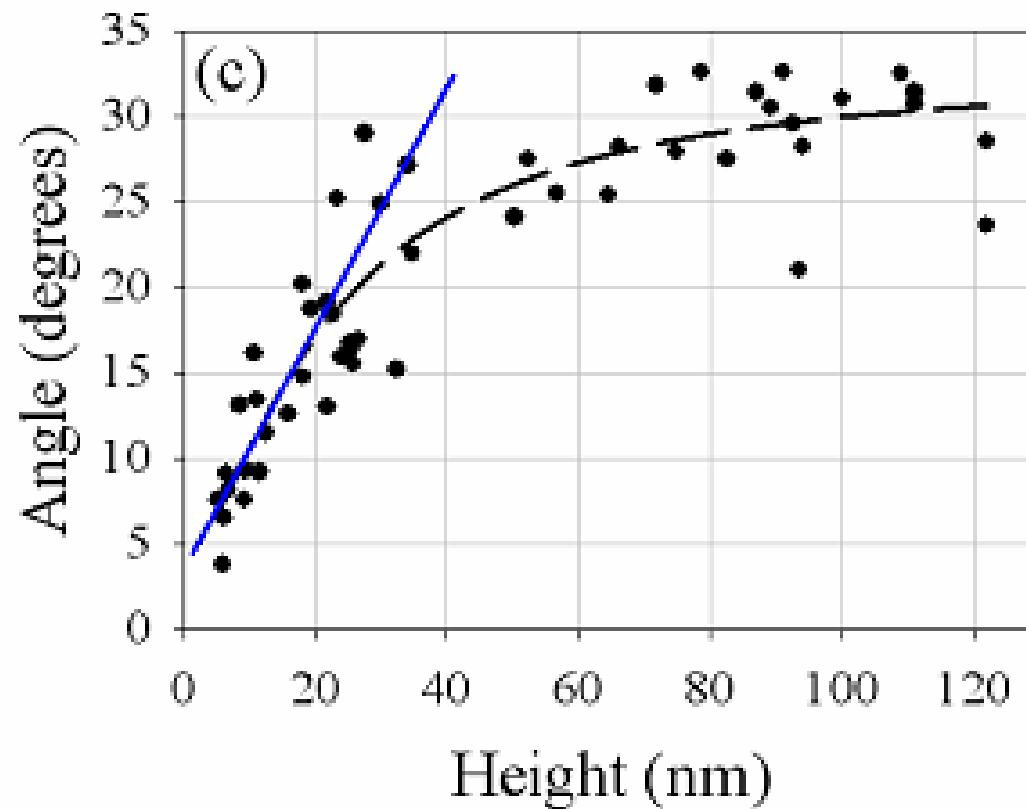
## *QD lateral and height aspect ratios*

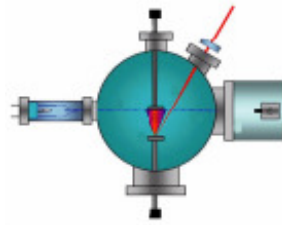






## *Variation of contact angle with QD height*





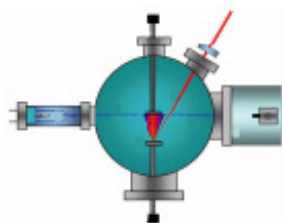
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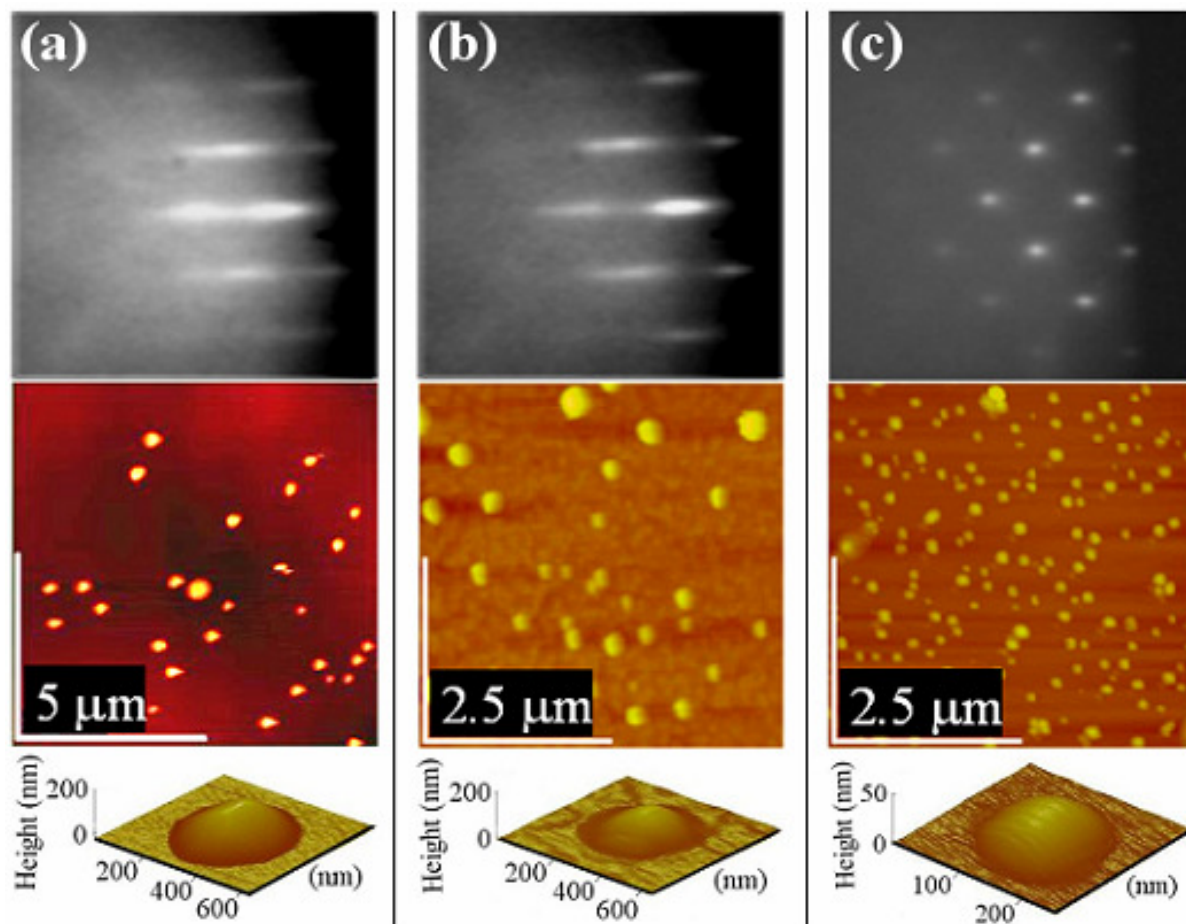
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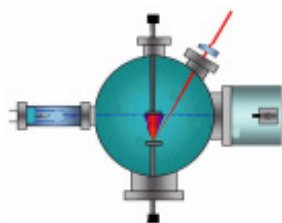
## ***II. Effect of laser fluence***



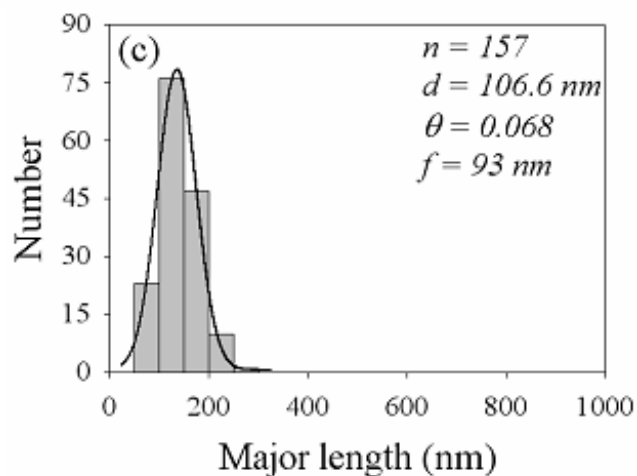
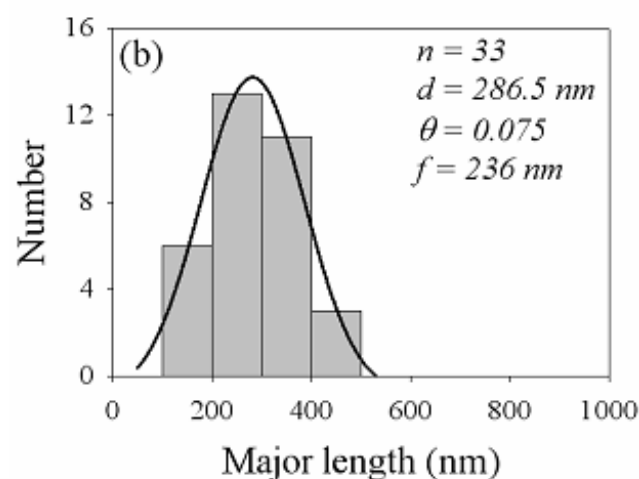
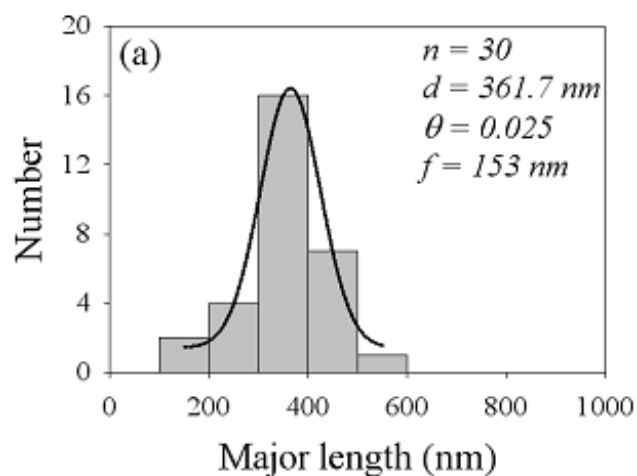
## *Shape, size and density change with fluence*



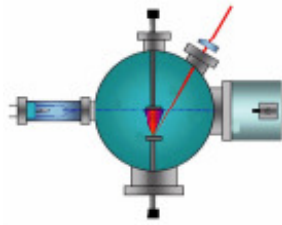
Deposition parameters: 400 °C, 10 Hz and column (a) 23 J/cm<sup>2</sup>, column (b) 47 J/cm<sup>2</sup>, column (c) 70 J/cm<sup>2</sup>



## *Shape, size and density change with fluence*



400 °C, 10 Hz and column (a) 23 J/cm<sup>2</sup>, column (b) 47 J/cm<sup>2</sup>, column (c) 70 J/cm<sup>2</sup>



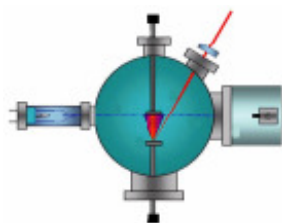
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# *III. Effect of temperature*

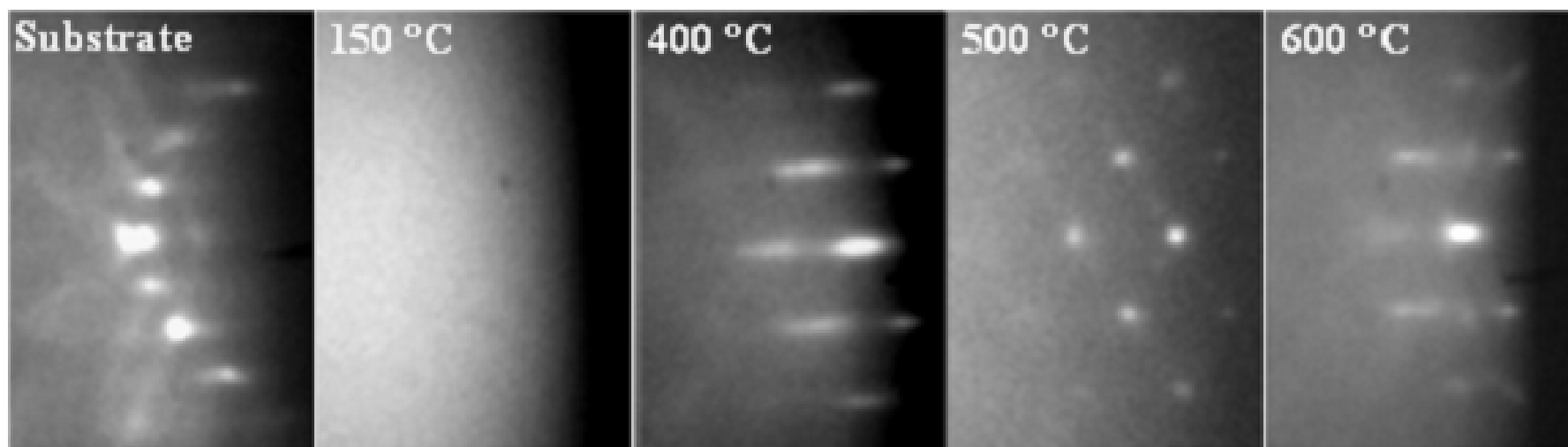


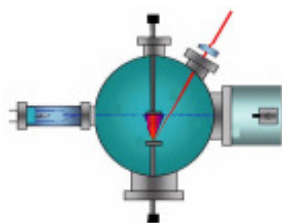
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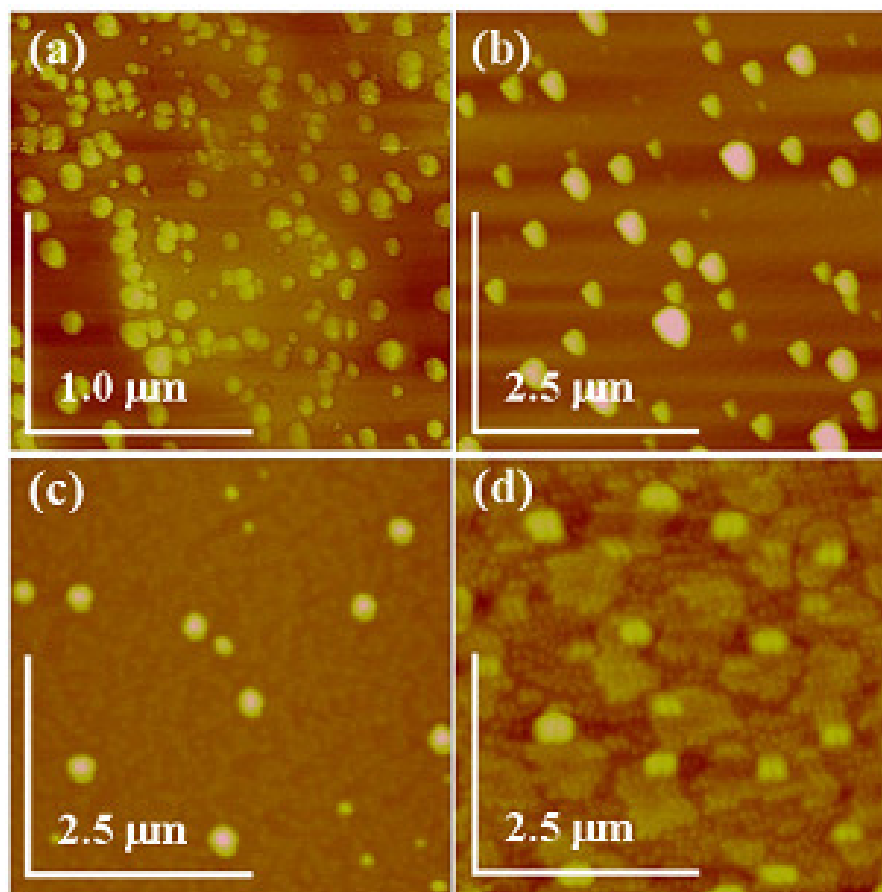
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## *RHEED detection of temperature effect*

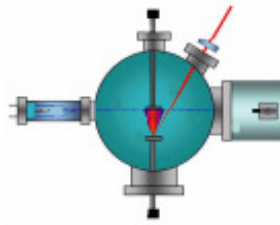




## *Temperature effect*



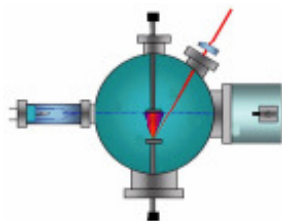
(a) 150 °C, (b) 400 °C, (c) 500 °C, (d) 600 °C



## Summary

- Growth dynamics of PLD of Ge QDs on Si(100)-(2x1) was studied by RHEED and AFM
- When the laser fluence is tripled, the QD density increased ~20 times, while the average lateral size decreased >3.5 times
- The shape also changed from large huts, observed at 23 J/cm<sup>2</sup>, to domes observed at the highest fluence
- At 150 °C, misaligned QDs formed resulting in diffused RHEED pattern. At 400 °C and 500 °C, transmission RHEED patterns were observed indicating the growth of oriented hut and dome QDs. Around 600 °C, the QDs were formed on top of some textured surfaces





## **For detailed information**

1. M. S. Hegazy and H. E. Elsayed-Ali, “**Growth of Ge quantum dots on Si by pulsed laser deposition,**” J. Appl. Phys. **99**, 53408 (2006) [Selected to appear on the Virtual Journal of Nanoscience and Technology, Vol. 13(11) (2006)].
2. M. S. Hegazy and H. E. Elsayed-Ali, “**Self-assembly of Ge quantum dots on Si(100) by pulsed laser deposition,**” Appl. Phys. Lett. **86**, 243204 (2005) [Selected to appear on the Virtual Journal of Nanoscience and Technology, Vol. 11, Issue 24, 2005].
3. M. S. Hegazy, T. R. Refaat, M. N. Abedin, H. E. Elsayed-Ali, “**Fabrication of GeSi quantum dot infrared photodetector by pulsed laser deposition,**” Optical Eng. Lett., **44(5)**, 59702 (2005)
4. M. S. Hegazy and H. E. Elsayed-Ali, “**Quantum-dot infrared photodetector fabrication by pulsed laser deposition technique,**” J. Laser Micro/Nanoengineering, *in press*.